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Improved Steganography Techniques For Different Types Of Secret Data

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Abstract: Steganography is an interesting aspect of data hiding art where the secret data such as (binary bits, logo, image, audio, and others) are embedded in a cover media without raising any suspicion about the existence of that data. Over the years, different steganography techniques for digital images have been presented to be applied in various applications such as security and privacy control. Some of these techniques are based on transforming the image from the spatial domain to the transform domain as a pre-processing step before embedding the secret data. This paper presents two improved steganography techniques in the transform domain based on Slantlet transform (SLT) and different data embedding methods. In the first proposed technique, a secret image can be embedded in a cover image by calculating the difference blocks of SLT coefficients and modifying the coefficients according to the root mean square error values. In the second proposed technique, a sequence of binary bits can be embedded in a cover image by modifying the carrier SLT subbands according to the secret data bits and the mean values of SLT coefficients for image's blocks. The experimental results proved the efficiency of the proposed techniques in comparison with the previous transform-based steganography techniques.

Keywords: Data hiding, Steganography, Slantlet transform, Security, Sharing secret data.

1. INTRODUCTION

Data hiding techniques are widely used in digital communication for different purposes such as security and privacy control [1]. The steganography [2-5] and watermarking [6,7] techniques are the two main parts of data hiding science. These techniques are based on hiding secret data in the cover media either by directly changing the contents of the cover media (i.e., embedding in spatial domain) or by transforming the cover media and embedding the secret data in the resultant coefficients after transformation (i.e., embedding in the transform domain). In the transform-based data hiding techniques, different transforms have been applied as a pre-processing step before embedding the secret data such as discrete cosine transform (DCT) [8, 9], discrete wavelet transform (DWT) [5, 10, 11], and an orthogonal DWT called Slantlet transform (SLT) [4,12,13].

On the other hand, the implementation of the steganography algorithm is affected by the type of secret data that is intended to be embedded in the cover image. In [14], a steganography algorithm has been presented to hide a secret text in a cover image by embedding each character from the text in a window of pixels of size 5×5 using a rule of non-multiples of 5. In [15], a secret text file is compressed and embedded in the pixels of the Red, Green, and Blue (RGB) channels of the color image. In [16], a text message is converted to a sequence of binary bits and embedded in the least significant bits (LSB) of the pixels in the cover image. In [4], another steganography technique has been introduced to embed binary bits in a cover image using Slantlet transform (SLT) [17] and two data

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embedding methods (i.e., LSB Substitution method and the threshold embedding method). The performance of the steganography technique has been improved in comparison with the DWT-based scheme, however, the visual quality of the stego images still needs more improvement.

Other steganography techniques have been presented to hide a secret image in a cover image. In [18], a secret image is embedded in the LSBs of a cover image which could be a color or grayscale image. The exclusive-or (XOR) of a block of pixels is used to determine the smoothness of the neighborhood in order to obtain the number of bits that can be embedded in the cover image. In [5], a DWT-based steganography technique has been presented to hide a secret image in a cover image. The technique converts the cover image and the secret image using DWT and the resultant coefficients are divided into 4-subbands named as approximation, horizontal, vertical, and the diagonal coefficients. Each subband is divided into non-overlapping blocks then the approximation coefficients of the secret image are compared with the approximation coefficients of the cover image and the root mean squared error (*RMSE*) is calculated to find the locations of the best similar blocks. The differences between these coefficients are calculated and saved as error blocks then the *RMSE* is used to find the locations of the best matched horizontal coefficients blocks with the error blocks, thereafter, the error blocks are embedded in the horizontal coefficients blocks.

The work in this research paper is directed towards the steganography techniques in the transform domain and its aims can be summarized as follows:

- Introducing an improved steganography technique to hide secret image in a cover image.
- Introducing another improved steganography technique to hide a sequence of binary bits in a cover image.

To meet the first aim of this work, the transform type (i.e., DWT) is changed to (SLT) in a previous steganography technique [5] while keeping the same data embedding method then the data embedding method is modified to improve the performance. To meet the second aim of this work, an improved steganography technique is introduced to hide a sequence of binary bits in a cover image by modifying the carrier SLT subbands according to the secret data bits and the mean values of SLT coefficients for the cover image's blocks.

The rest of the paper is organized as follows: section 2 explains the implemented algorithms, section 3 illustrates the experiments and their discussion, and section 4 contains the conclusion.

2. THE IMPLEMENTED TECHNIQUES

The following subsections presents the steps of the proposed algorithms in this paper. The first algorithm (SLT-EM1) is implemented to hide a secret image in a cover image using SLT and an embedding algorithm from [5]. Then the same algorithm has been modified to improve the performance in terms of visual quality and the modified algorithm is named as SLT-MEM1. The second steganography algorithm has been implemented to embed a sequence of binary bits in a cover image and it is named as SLT-EM2. The abbreviations of the proposed algorithms can be explained as follows:

- SLT-EM1: refers to Slantlet Transform and Embedding Method 1.
- SLT-MEM1: refers to Slantlet Transform and Modified Embedding Method 1.
- SLT-EM2: refers to Slantlet Transform and Embedding Method 2.

2.1. SLT-EM1

The algorithms of SLT-EM1 for the secret image embedding and extraction processes are summarized in Fig. 1 and Fig. 2, respectively. The detailed steps are explained in the following subsections.

2.1.1. SLT-EM1 data embedding procedure

Step 1: Read the original cover image (I_o) and the secret image (I_s).

Step 2: Apply the 2D-SLT to I_o and divide the resulting coefficients into four subbands ($CA, CH, CV, and\ CD$).

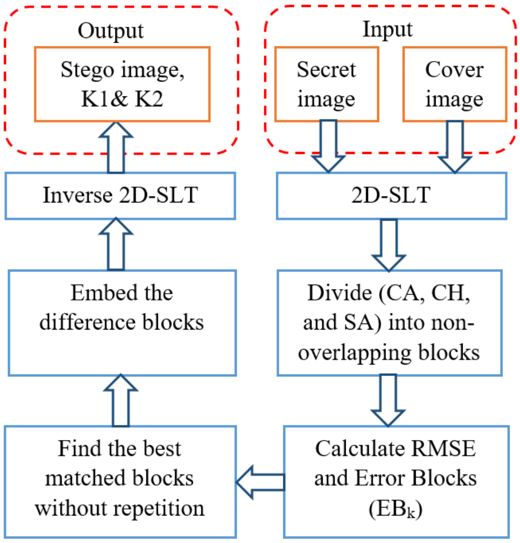


Fig. 1. SLT-EM1 data embedding procedure

Step 3: Apply the 2D-SLT to I_s and divide the resulting coefficients into four subbands ($SA, SH, SV, and\ SD$).

Step 4: Divide $CA, CH, and\ SA$ subbands into non-overlapping blocks of size 4×4. The subbands' blocks can be represented as follows:

$$CA = \{BA_i, 1 \le i \le n\}$$
$$CH = \{BH_i, 1 \le i \le n\}$$
$$SA = \{BS_k, 1 \le k \le n_s\}$$

Where BA_i is the i^{th} block in CA , BH_i is the i^{th} block in CH , and BS_k is the k^{th} block in SA, n is the total number of 4×4 blocks in CA and in CH , n_s is the total number of 4×4 blocks in SA.

Step 5: Calculate the $RMSE$ to find the best matched block BA_i with BS_k , save the locations i of these best matched blocks in a secret key K_1.

Step 6: Calculate the difference (i.e., error block) EB_k between BA_i and BS_k as follows:

$$EB_k = BA_i - BS_k \quad \ldots(1)$$

Step 7: For each block in EB_k , use the $RMSE$ to find the best matched block BH_i; save the locations i of these best matched blocks in a secret key K_2. Then replace BH_i with EB_k.

Step 8: Continue to embed all the difference blocks in CH then replace the original CH subband with the new CH subband.

Step 9: To obtain the stego image G apply the inverse 2D-SLT to ($CA, new\ CH, CV, and\ CD$).

The previous algorithm in [5] searches for the locations of the best matched blocks to obtain (K_1 and K_2) but some of the locations may be repeated more than once and this will cause losing some of the error blocks (because they will be embedded in the same location). To avoid this problem, the embedding algorithm in this paper has been modified to check the locations that has been obtained and if the same location appeared again then the location of the next block with the minimum $RMSE$ must be found.

2.1.2. SLT-EM1 data extraction procedure

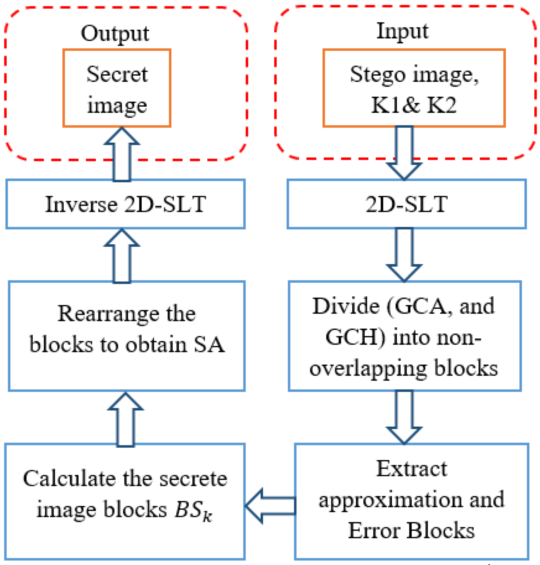


Fig. 2. SLT-EM1 data extraction procedure

Step 1: Apply the 2D-SLT to the stego image G and divide the resulting coefficients into four subbands ($GCA, GCH, GCV, and\ GCD$).
Step 2: Divide $GCA, and\ GCH$ into non-overlapping blocks of size 4×4. The blocks can be represented as follows:

$$GCA = \{BA_i, 1 \le i \le n\}$$
$$GCH = \{BH_i, 1 \le i \le n\}$$

Step 3: Use secret key K_1 to find the BA_i and use the secret key K_2 to extract the error blocks EB_k from BH_i. The secret image block BS_k can be recovered as follows:

$$BS_k = BA_i - EB_k \qquad \ldots(2)$$

Step 4: Repeat (step 3) to extract all the secret blocks. Rearrange the blocks to obtain SA.
Step 5: Set $SH, SV, and\ SD$ as zeros then apply inverse 2D-SLT to ($Extracted\ SA, SH, SV, and\ SD$) to obtain the secret image.

To embed the secret image in $CV, or\ CD$ subbands, the same procedures can be used but the CH subband must be replaced by the required subband.

In order to improve the visual quality of the stego image, the embedding algorithm is modified and the technique is named as SLT-MEM1. In the modified algorithm the error blocks are divided by a variable α and the procedure of the embedding process (section 2.1.1) is the same but in step 6 the following equation will be used:

$$EB_k = \frac{1}{\alpha}(BA_i - BS_k) \quad \ldots(3)$$

In the extraction process (section 2.1.2) the same procedure repeated but in step 3 the following equation will be used:

$$BS_k = BA_i - \alpha \times EB_k \quad \ldots(4)$$

2.2. The proposed steganography technique (SLT-EM2)

The previous study of SLT-EM1 and SLT-MEM2 proved that SLT performs better in comparison with DWT, therefore it will be adopted in the proposed steganography technique (SLT-EM2) in which a new data embedding method is suggested in order to improve the performance. The proposed embedding process depends on modifying the carrier SLT subband according to the secret data bit and the mean value of SLT coefficients in a block. The algorithms of SLT-EM2 for the secret data embedding and extraction processes are summarized in the block diagrams shown in Fig. 3 and Fig. 4, respectively. The steps of the algorithms are detailed in the following subsections.

2.2.1. SLT-EM2 data embedding procedure

Step 1: Apply 2D-SLT to the cover image (I_m) and divide the coefficients into four subbands ($CA, CH, CV, and\ CD$).

Step 2: Divide each subband ($CH, CV, and\ CD$) into non-overlapping blocks of size ($B_s \times B_s$) as follows:

$$CH = \{BCH_i,\ 1 \le i \le nc\}$$
$$CV = \{BCV_i,\ 1 \le i \le nc\}$$
$$CD = \{BCD_i,\ 1 \le i \le nc\}$$

Where BCH_i is the i^th block in *CH*, BCV_i is the i^th block in *CV*, BCD_i is the i^th block in *CD*, *nc* is the total number of ($B_s \times B_s$) blocks in each subband.

Step 3: Calculate the mean value of the coefficients in each block as follows:

$$M_{block} = \frac{1}{B_s^2}\sum_{x=1}^{B_s}\sum_{y=1}^{B_s} C_{x,y} \quad \ldots(5)$$

$$Mean\ CH = \{MCH_i,\ 1 \le i \le nc\}$$
$$Mean\ CV = \{MCV_i,\ 1 \le i \le nc\}$$
$$Mean\ CD = \{MCD_i,\ 1 \le i \le nc\}$$

Where M_{block} is the mean value for the block of size $B_s \times B_s$, $C_{x,y}$ is the SLT coefficient in the coordinates (x, y), MCH_i is the mean value of the i^th block in CH, MCV_i is the mean value of the i^th block in CV, MCH_i is the mean value of the i^th block in CD.

Step 4: The rules of the proposed data embedding method can be explained as follows:

- Each bit from a binary sequence of data (w_k) {where k=1, 2, …, Length (w)} can be embedded using two successive blocks. The main idea of the proposed data embedding process is that, when w_k is '1' then the mean value of the first block should be more than the mean value of the second block, when w_k is '0' the reverse is true. The embedding process in CH will be explained and the same idea can be applied for embedding data in CV and CD.
- To embed a binary bit w_k in two successive blocks the mean values of these blocks will be used to control the embedding process as follows:

Let $x_1 = MCH_i$, $x_2 = MCH_{i+1}$

If $w_k = 1$ *and* $x_1 < x_2$, then exchange the blocks BCH_i *and* BCH_{i+1}

Else if $w_k = 1$ *and* $x_1 \geq x_2$, then do nothing;

If $w_k = 0$ *and* $x_2 < x_1$, then exchange the blocks BCH_i *and* BCH_{i+1}

Else if $w_k = 0$ *and* $x_2 > x_1$, then do nothing;

This process must be repeated until embedding all data bits.

Step 5: Rearrange the blocks to construct the modified subbands.

Step 6: Apply inverse 2D-SLT to obtain the stego image.

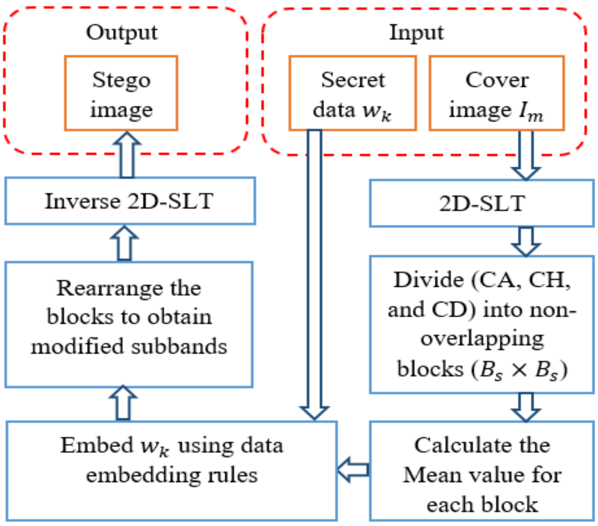


Fig. 3. SLT-EM2 data embedding procedure

2.2.2. SLT-EM2 data extraction procedure

Step 1: Apply the SLT to the stego image (G) and divide the coefficients into four subbands ($GCA, GCH, GCV, and\ GCD$).

Step 2: Divide each subband ($CH, CV, and\ CD$) into non-overlapping blocks of size ($B_s \times B_s$) as explained in (section 2.2.1, step 2).

Step 3: Calculate the mean value of the coefficients for each block in subband as explained in (section 2.2.1, step 3).

Step 4: The length of the data is required at the receiver side where the data bits can be extracted as follows:

$$w_k = \begin{cases} 1, & if\ \ MCH_i \geq MCH_{i+1} \\ 0, & if\ \ MCH_i < MCH_{i+1} \end{cases},\ for\ k = 1, 2, \ldots, length(w)$$

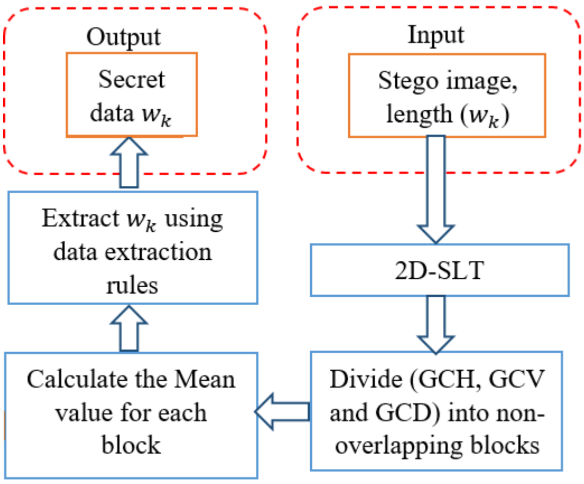


Fig. 4. SLT-EM2 data extraction procedure

3. THE EXPERIMENTAL RESULTS AND DISCUSSION

This section presents the experiments that have been conducted to evaluate the implemented algorithms: SLT-EM1, SLT-MEM1 and SLT-EM2. The first subsection contains the performance evaluation of the implemented algorithms (SLT-EM1 and SLT-MEM1) in comparison with the DWT-based technique from [5]. The second subsection contains the performance evaluation of the proposed technique (SLT-EM2) in comparison with the previous SLT-based technique from [4]. In [4,5], the metric that have been used to evaluate the visual quality of the stego image is the Peak Signal-to-Noise Ratio (PSNR), therefore, the same metric is adopted here to make the comparison valid.

3.1. Experimental Results of SLT-EM1 and SLT-MEM1

For comparison purpose, the same test images that have been used in [5] are utilized in the experiments of this section. The cover images (Peppers, Goldhill, Cameraman, and Barbara) are shown in Fig. 5 where each image is of size (256×256) pixels. Fig. 6 contains the secret images (Airplane and Bird) with size (128×128) pixels.

(a) (b) (c) (d)

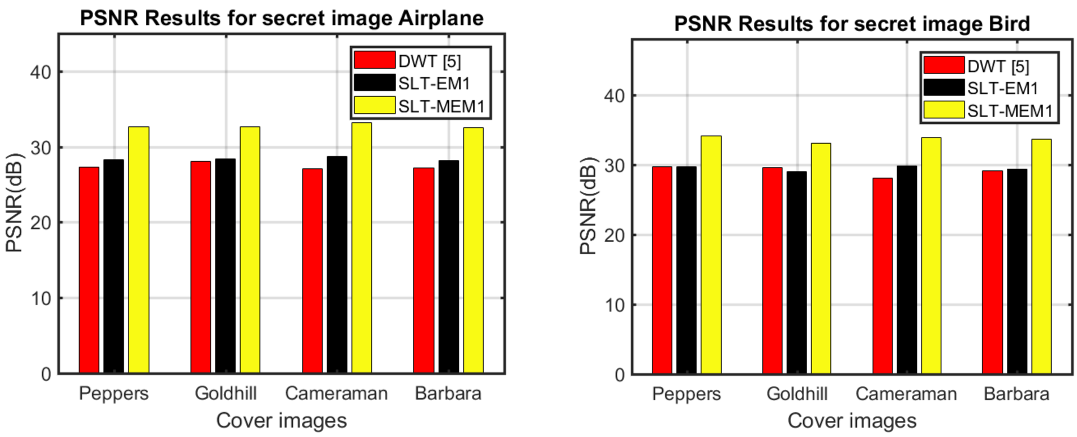
Fig. 5. Cover images: (a) Peppers, (b) Goldhill, (c) Cameraman, and (d) Barbara.

(a) (b)

Fig. 6. Secret images: (a) Airplane, and (b) Bird.

The secret images are embedded in *CH* subband of the cover images using (SLT-EM1 and SLT-MEM1); α in SLT-MEM1 is set to 2 (as an example). Fig. 7 presents the PSNR results of the stego images for the two secret images (i.e., Airplane and Bird). The results proved that, replacing the DWT by SLT improved the visual quality results of the stego images, however, further improvement has been obtained using SLT-MEM1 in which the embedding method has been modified.

The PSNR between the original secret image and the extracted secret image has been calculated to evaluate the quality of the extracted secret image and the results are shown in Table 1. As illustrated in the results, the extracted secret images using SLT-EM1 and SLT-MEM1 obtained better visual quality results in comparison with the DWT-based scheme [5]. The difference between SLT-EM1 and SLT-MEM1 is only in the embedding process, therefore, the same secret information is embedded and extracted and this is proved in the results of Table 1.



(a) (b)

Fig. 7. PSNR(dB) results for the stego images when the secret image: (a) Airplane, and (b) Bird.

Table 1 The PSNR (dB) of the extracted secret images from *CH* subband

Cover images (256×256)	Secret images (128×128)					
	Airplane			Bird		
	DWT [5]	SLT-EM1	SLT-MEM1	DWT [5]	SLT-EM1	SLT-MEM1
Peppers	22.3544	25.2799	25.2796	28.8265	32.0501	32.0500
Goldhill	22.3544	25.2793	25.2793	28.8265	32.0506	32.0502
Cameraman	22.3544	25.2794	25.2795	28.8265	32.0505	32.0502
Barbara	22.3544	25.2791	25.2791	28.8265	32.0500	32.0500

The effect of embedding the secret images in different subbands ($CH, CV, and\ CD$) of the cover images has been studied and the results of SLT-EM1 and SLT-MEM1 are shown in Table 2 and Table 3, respectively. As illustrated in Table 2 and Table 3, the obtained results for *CH* and *CV* subbands are convergent and both are better than the results of *CD* subband; on the other hand, the SLT-MEM1 technique obtained better results in comparison with SLT-EM1 technique.

Table 2 The PSNR(dB) results for the stego images at different subbands using SLT-EM1

Cover images (256×256)	Secret images (128×128)					
	Airplane			Bird		
	CH subband	*CV* subband	*CD* subband	*CH* subband	*CV* subband	*CD* subband
Peppers	28.2451	28.4586	27.8485	29.6938	29.6936	29.1933
Goldhill	28.3697	28.2927	27.7174	29.0134	29.2456	28.4965
Cameraman	28.6842	28.8816	27.7867	29.8682	30.0028	29.2273
Barbara	28.1230	28.2932	27.7850	29.4041	29.6504	29.0477

Table 3 The PSNR(dB) results for the stego images at different subbands using SLT-MEM1

Cover images (256×256)	Secret images (128×128)					
	Airplane			Bird		
	CH subband	*CV* subband	*CD* subband	*CH* subband	*CV* subband	*CD* subband
Peppers	32.6267	32.7314	32.3668	34.1096	33.9971	33.2923
Goldhill	32.6697	32.5951	32.0575	33.0514	33.2603	32.4745
Cameraman	33.1888	33.3216	32.5160	33.8336	33.8251	33.3362
Barbara	32.5431	32.6211	32.2960	33.6547	33.7584	33.4449

3.2. Experimental Results of SLT-EM2

In order to prove the efficiency of the proposed data embedding method, the experiments have been conducted to compare the performance of the proposed SLT-based steganography scheme with a previous SLT-based steganography scheme from [4] which used two different embedding methods (i.e., LSB and threshold).

For comparison purposes, the experiments have been conducted for the same test image (i.e., grayscale Lena image) that has been used in [4]. In the proposed steganography scheme (SLT-EM2), different block sizes can be used and the data can be embedded in different subbands, therefore, the experiments have been conducted to evaluate the visual quality for the three subbands ($CH, CV, and\ CD$) at different block sizes ($B_s \times B_s$). Fig. 8 and Fig. 9 present the experimental results and comparison with the LSB embedding method from [4] for the payload (36 bits) at block size (2×2) and block size (4×4), respectively. The results proved that the stego image using the proposed SLT-EM2 technique obtained better visual quality results in comparison with the LSB embedding method. The highest *PSNR* values are obtained when the secret data is embedded in CD subband. On the other hand, the results proved that in SLT-EM2, the lower the block size the better the visual quality results because less changes will be conducted in the stego image.

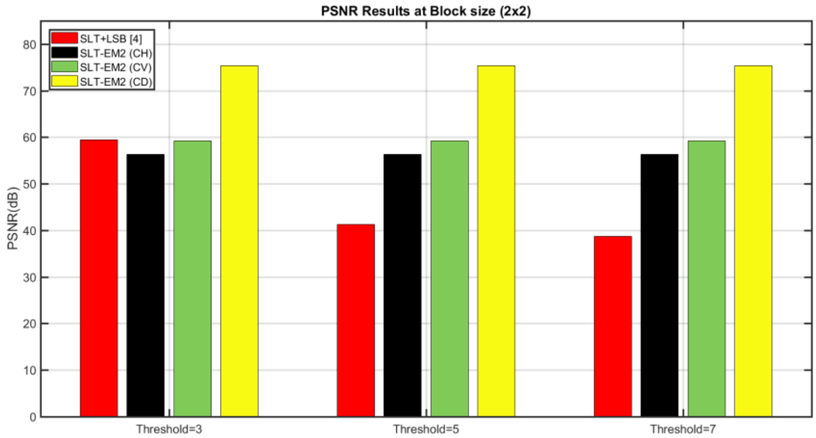


Fig. 8. Visual quality comparison of SLT-EM2 with LSB method at block size (2×2).

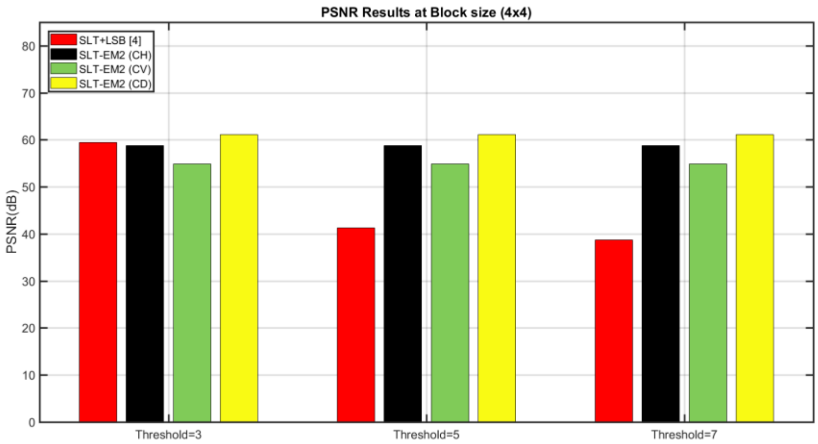


Fig. 9. Visual quality comparison of SLT-EM2 with LSB method at block size (4×4).

To compare the performance of SLT-EM2 and the threshold embedding method from [4], the same previous experiments have been conducted but the payload is changed to (44 bits). Fig. 10 and Fig. 11 present the experimental results which proved that the proposed SLT-EM2 technique obtained better visual quality results in comparison with the threshold embedding method.

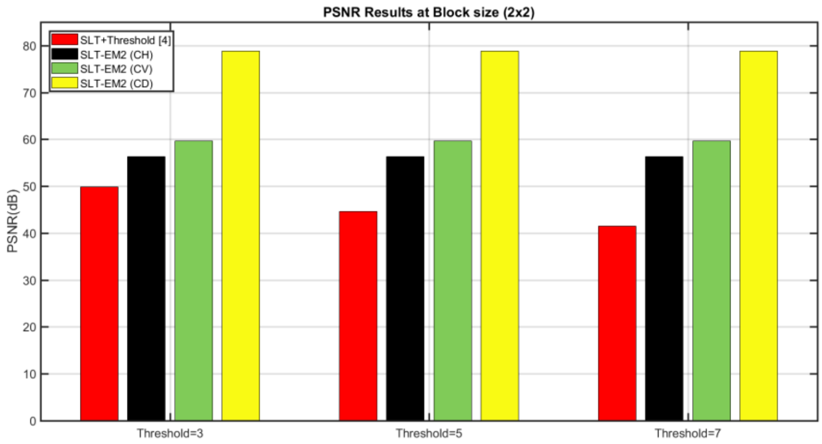


Fig. 10. Visual quality comparison of SLT-EM2 with threshold method at block size (2×2).

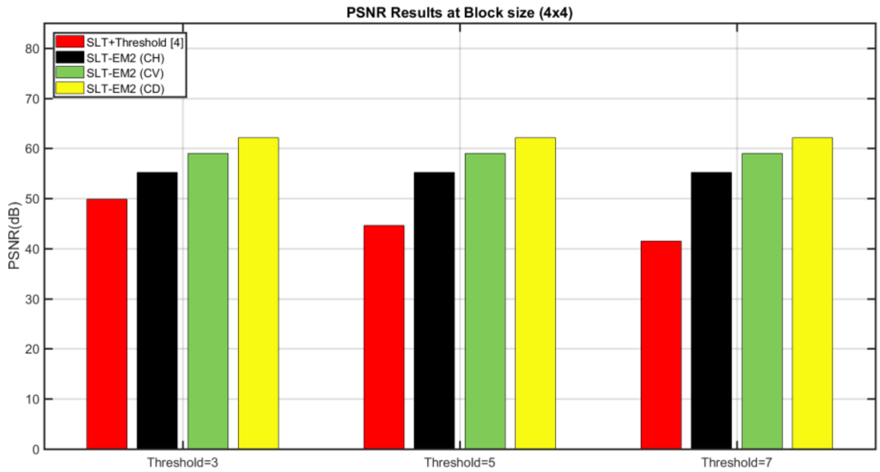


Fig. 11. Visual quality comparison of SLT-EM2 with threshold method at block size (4×4).

The visual quality using SLT-EM2 has been tested at higher payloads and the comparison results are illustrated in Table 4. The results proved that for higher payloads the stego image using SLT-EM2 has better visual quality in comparison with LSB and threshold embedding methods.

Table 4 Visual quality comparison at higher payloads

Payload (bits)	Threshold Embedding [4]	LSB Embedding [4]	SLT-EM2
1000	—	—	39.8666
1673	24.6087	25.8256	36.7899
3727	24.6042	25.8249	31.7497
4000	—	—	31.1905

Another experiment has been conducted to evaluate the error level in the extracted binary bits for the proposed algorithm SLT-EM2 by calculating the normalized correlation (NC) between the original bits and the extracted bits. Table 5 presents the NC results for binary sequences of length (1000 and 1500 bits) which are embedded in the test images that have been used in the previous experiments (i.e., Lena, Peppers, Goldhill, Cameraman, and Barbara) at block sizes (2×2 and 4×4). The results proved that there is a small amount of error in the extracted bits which is resulted from the rounding operation due to the embedding in the transform domain.

Table 5 Normalized Correlation (NC) results

Test image	Binary Sequence (1000 bits)		Binary Sequence (1500 bits)	
	block size (2×2)	block size (4×4)	block size (2×2)	block size (4×4)
Lena	0.8960	0.9580	0.9150	0.9680
Peppers	0.9520	0.9530	0.9520	0.9467
Goldhill	0.9620	0.9860	0.9707	0.9575
Cameraman	0.8940	0.9201	0.8933	0.9094
Barbara	0.9500	0.9600	0.9402	0.9494

4. CONCLUSION

This paper presents two improved steganography techniques based on SLT and different embedding methods. The first proposed technique embeds secret image in a cover image while the second proposed technique embeds binary data in a cover image. The work in this paper proved that the change of the transform type while using the same data embedding method can improve the visual quality of the stego images, on the other hand, the change of the data embedding method while applying the same transform type can also improve the performance of the steganography technique. The experimental results of the first technique proved that the SLT-based steganography techniques perform better in comparison with the DWT-based techniques. In addition, the modification of the embedding algorithm causes further improvement in the results. The experimental results of the second technique proved the efficiency of the proposed technique in comparison with a previous SLT-based steganography technique. From the work presented in this paper, one can conclude that the researcher who intend to implement a new steganography technique in the transform domain should investigate the performance of his / her technique using different transforms to choose the best transform that can match the embedding method to obtain the optimum results.

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